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GPC: latest developments and applications

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Efficient wavefront sculpting of light has a variety of contemporary applications in both research and industry. With the widespread use of lasers that lend themselves to efficient reshaping due to their high spatial coherence, the versatility of wavefront sculpting is further increased. Spatial laser beam modulation based on photon-efficient phase-only methods are extensively applied in advanced microscopy and contemporary optical trapping and manipulation [1,2] to mention some typical applications. Phase-only light shaping is also finding its use in new and exciting applications such as for emerging neurophotonics applications and in fully parallel two-photon optogenetics [3] which applies the most advanced optical tools for exploring neuro-scientific challenges. Beyond the R&D uses, efficient light shaping is also desirable for applications such as laser machining, lithography and future laser-based digital cinemas to name a few. These diverse applications all require light to be shaped in a plurality of ways [4]. For example, the illuminated optical window of spatial light modulators, used for both optics research and consumer display projectors, have a rectangular form factor. A variety of shapes bounded by steep edges and particular point spread functions are desirable in laser materials processing. For two-photon optogenetics [5], it is a key aim to selectively illuminate intricate patterns of dendrites or axons within neurons, preferably with minimal loss of light and maintaining speckle-free light excitations even within turbid media.

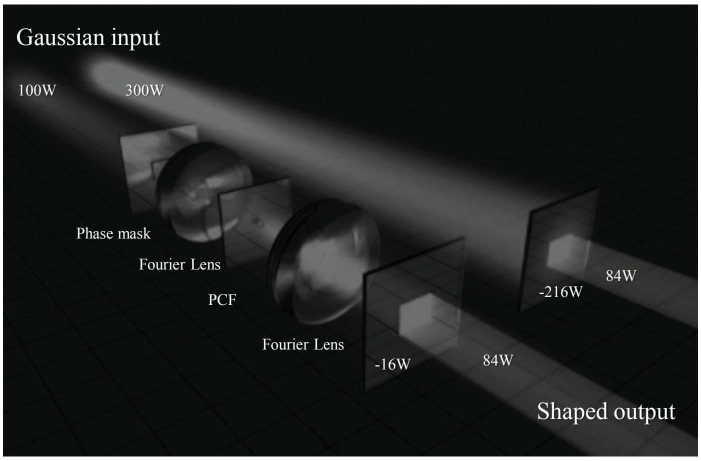

Figure 1: GPC (Generalized Phase Contrast) efficiently transforms an incident Gaussian beam into a bright shaped output using only simple binary spatial phase modulation. For comparison an amplitude masking configuration is shown besides a GPC Light Shaper to illustrate the significant difference in energy utilization when aiming for the same shaped output. (Figure adapted from [6])

Laser sources typically exhibit a Gaussian intensity profile. Shaping such a beam with the commonly applied hard truncation is inherently highly inefficient. It is well known that more than two thirds of an incident power will be lost when homogenously illuminating a rectangular aperture with an expanded Gaussian beam [6-8]. To complicate things, this lost light power will inherently contribute to device heating that can either shorten device lifespan or require additional power for active cooling. Besides the obvious disadvantages of light inefficiency, the high price tag of advanced laser sources, such as femtosecond lasers or supercontinuum sources, used for multi-photon excitation, multi-spectral biophotonics and other state-of-the-art experiments, demands efficient use of the available photons

As for the technical implementation, the GPC-setup belongs to the class of non-absorbing common-path architectures [9]. A phase-only aperture is mapped directly pixel-by-pixel through the interference of its high and phase-shifted low spatial frequencies. This is achieved by phase shifting the lower spatial frequencies through a binary phase contrast filter (PCF) at the optical Fourier plane (cp. Fig. 1). Hence, GPC can be implemented with binary phase plates that are inherently simple to mass-produce with standard foundry processes common for silicon devices or microelectronics. The use of a one-to-one mapping geometry in GPC inherently avoids dispersion effects which makes it advantageous for use with multiple wavelengths [10,11], spectrally broad light sources or for temporal focusing which can effectively confine light along the axial direction. Most recently, GPC has been demonstrated with its inherent adaptivity for boosting computer holographic reconstructions encoded on reconfigurable spatial light modulators [12].

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